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Olfactory temporal double-alternation in laboratory rats

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OLFACTORY, TEMPORAL, DOUBLE-ALTERNATION IN LABORATORY RATS

By

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B.A., University of Montana, 1973

Presented in partial fulfillment of the

requirements for the degree of

Master of Arts

UNIVERSITY OF MONTANA

1974

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April 3, 1975

Date

Cress, Mark A., M.A., 1974 Psychology

Olfactory, Temporal, Double-alternation in Laboratory Rats

Director:

This study represents a procedural transition through three separate olfactory, temporal, double-alternation experiments from an unsuccessful apparatus to one where moderate success was achieved on the double-alternation problem. There was no indication in Experiment I that the rat was capable of double-alternation in the traditional temporal maze when airborn olfactory cues were added. Experiments II and III introduced a procedural innovation which was better suited to the presentation of olfactory stimuli to the rat. The instrumental response required the manipulation of the stimulus object laden with odor and assured the subjects direct contact with the olfactory cues. Using this procedure in an apparatus with visual and spatial-separation cues, Experiment II allowed the rat to double-alternate up to levels of 35.0% correct over ten consecutive trials. With the addition of olfactory cues performance was improved up to levels of 59.5% correct over ten consecutive trials. In Experiment III, further refinements in the apparatus removed all visual and spatial cues and on the basis of olfactory information alone, rats double-alternated at levels up to 72.7% correct over 50 consecutive trials and as high as 81.6% correct over ten consecutive trials.

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CHAPTER I

INTRODUCTION

Double alternation is a sequence of behavior consisting of alternating between pairs of responses. For example, turning left, right, left, right would be a single-alternation sequence, while turning left, left, right, right would be a double-alternation sequence. Double alternation has proved to be extremely difficult for the rat when compared to other mammals. Livesey (1965) for example, used a Wisconsin General Test Apparatus (WGTA) to compare rats with cats and rabbits on double-alternation problems. While rats required 520 to 700 sequences to reach criterion (80% correct over 50 sequences), rabbits and cats required significantly fewer trials: 180 to 420 and 150 to 360, respectively. In a similar experiment by Johnson (1961), raccoons required less than 270 sequences to reach criterion.

The only report of a double-alternation sequence longer than four responses by the rat is an unpublished Ph.D. thesis (Woodbury, 1948). Cats have been reported to learn sequences of six responses (rrllrr). Rhesus monkeys (Livesey, 1969) extended double-alternation behavior to sequences of eight to twelve responses.

The typical apparatus used in double-alternation studies is an enclosed maze of either spatial or temporal design. In the spatial maze (Andrews and Hunter, 1943; Casper, 1933; Dennis, 1931; Hunter and Hall, 1941), the subject proceeds from the choice point after a correct response to a different choice point. This creates a series of distinct problems. A spatial maze is often set up in blocks which can be rotated and interchanged (Andrews and Hunter, 1943; Dennis, 1931; Hunter and Hall, 1941). Andrews and Hunter (1943) found that rats failed when this interchange took place, but could learn the double-alternation sequence when the blocks remained stationary. An experiment by Ludvigson and Systma (1967) showed that without this interchange odor cues aid in the discrimination of the correct response.

The temporal maze requires an animal to make all choices at the same choice point. After a response an animal must run around an exterior arm of the maze which returns him to the original choice point. In this way, an animal is presented with the same problem four times and must respond in different ways. Because of this, external cues cannot be used to determine the appropriate response. The animal must remember the sequence in order to respond correctly.

Studies have shown that animals differ greatly in their ability to master this behavior. Gellerman (1931) ran untrained monkeys in the temporal maze. Six year olds mastered the double-alternation sequence in an average of 18.3 trials, five year olds in 22.4 trials. The ability of these five-year-old monkeys is equivalent to that of young children. Monkeys also show the ability to extend these response sequences to eight and twelve responses. Raccoons could approach this level only after considerable pretraining. The raccoon has difficulty extending the sequence past four responses, but can do so (Hunter, 1928; Gellerman, 1931). Cats appear to be slightly less able than raccoons in mastering the temporal maze (Karn, 1938).

In contrast to these animals' abilities, the double-alternation temporal maze problem is virtually impossible for the rat. Hunter (1920) ran 550 double-alternation trials with white rats in a temporal maze and reported no progress towards mastery. He then used punishment with shock grids in 512 training trials and reported no progress. He concluded that the rat is incapable of double-alternation in the temporal maze. In another experiment (Hunter, 1918), rats readily learned a ten-response double-alternation sequence in ten separate T boxes, but when transferred to a single temporal maze of the same size and design, they showed no progress towards mastery in 500 to 600 trials. Hunter's response sequences usually consisted of eight rather than four responses. This may have had some effect on his results.

Hunter and Nagge (1931) managed, with a minimum of success, to train rats to double-alternate in a temporal maze using a four response sequence. They ran their rats through a sequence of controls which was essentially an elaborate training program. After this complex training, 14 of 20 rats made at least 3 perfect runs in succession. Five rats were perfect on their first test trial. None of the 14 could extend the sequence past 4 responses. They all responded llrrrrrr. Hunter concluded that while rats could use the cue of turning left for a left turn, they could not use that cue for both a left and a right turn. Gallup and Diamond (1966) stated that "though rats double-alternate in spatial mazes and in modified Skinner boxes, they are incapable, according to the preponderance of evidence today, of learning to do so in a temporal maze." Hunter (1929) gave a good example of the rat's ability in the temporal maze compared to their ability in the spatial maze. In this study, blinded rats, with their vibrissae cut, were tested in a spatial maze. Four of the six made correct responses in 7 to 43 trials. Unblinded rats in a similar maze (Hunter, 1920) reached mastery in 5 to 12 trials. In Hunter's (1929) experiment, rats previously trained in a spatial maze mastered a tridimensional double-alternation maze in from 10 to 115 trials. Two of these rats, even after they had run many successful trials on spatial mazes, could not make one correct llrr response in the temporal maze. The remaining three had isolated and insignificant responses. No rat mastered the temporal maze problem.

Munn (1971) stated:

> On this test the rat fails completely, even after 1,000 trials spread over several months. Raccoons on the other hand, solve the problem in about 500 trials, and cats and dogs do about as well. Monkeys and chimpanzees learn this type of problem in about 100 trials. Children under three have failed it, but beyond this age, it is learned with fewer trials in successively older groups of children. The average number of trials required by a group of 38 children ranging in age from three to thirteen was approximately 15. On the same test, college students require an average of 6 trials. (p. 130)

Olfaction

All the preceding studies presented double-alternation as primarily a visual problem, but even here, the strong influence of olfaction on the behavior of the rat required strict controls to prevent the data from being influenced by odors (Ludvigson and Systma, 1967; Phillips and Bloom, 1971).

Results obtained by Tapp and Long (1968) indicate olfaction may represent a sensory idiom more important to the behavior of the rat than visual, auditory, or tactile cues. They compared the reinforcing properties of the onset of different stimuli to determine the tendency of the subject to use a particular modality as a source of information about an environment. In 240 male albino rats, both deprived and satiated, the onset of an odor was preferred to the onset of a light, a tone, or a puff of air.

A study by Thorne and O'Brien (1971) gave further indication of the strength of olfactory stimuli on the rat's behavior. They presented 22 male albino rats with both visual and olfactory discrimination problems in a miniature WGTA. The rats learned the olfactory discrimination problem despite the fact that visual cues were relevant and obvious. They concluded that "most rats will use an olfactory cue in preference to a visual one when both are relevant to the discrimination."

Hypothesis

As Jennings and Keefer (1969) stated:

> . . . an organism which relies heavily on the olfactory modality should reflect this reliance in its ability to learn tasks where odor is the critical stimulus.

In spite of the poor showing of the rat as a double-alternator, the successes of Jennings and Keefer (1969) and of Langworthy and Jennings (1972) in obtaining evidence of abstract problem solving in rats using olfactory problems suggested that if the rat confronted olfactory double-alternation, it might master the problem.

CHAPTER II

EXPERIMENT I

Method

Subjects. The subjects (S) were 18 hooded rats. They were given 15 days of pre-experimental handling without gloves. During this gentling period, they were allowed to run daily on a table top covered with blocks and masonite partitions; these were rearranged daily. The Ss were divided into three groups and housed together in pairs.

Apparatus. The apparatus was a modification of that used by Diamond (1967). It was a temporal maze shaped like the Greek letter Theta (see Figure 1). This design required the animal to make his turns at the same choice point on each trial, and always pass the point of reinforcement in order to complete a sequence of turns. In this way, the animal could not use external cues; it had to make all its choices from stimuli within itself, ignoring external stimuli.

The maze was constructed of masonite partitions on a plywood base. Its external dimensions were the same as those used by Diamond (1967)--42 inches by 32 inches. The walls were 15 inches high and the alleys were 4 inches across. There were two clear plexiglas doors, one at each end of the center alley, which were manipulated from outside the maze by wires. They were situated in such a way that the one at the choice point could be moved to direct the animal either right

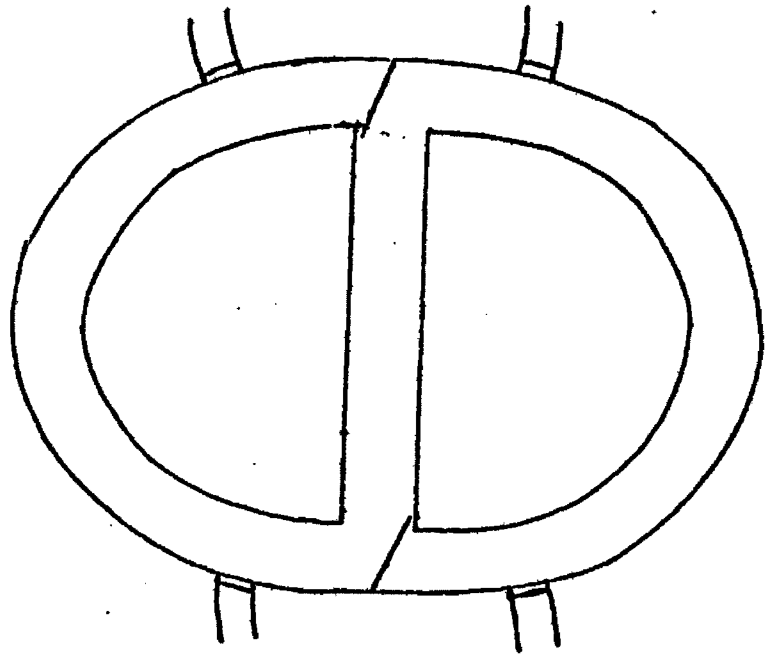

Figure 1. Olfactory, Temporal, Double-alternation Maze, Experiment I

or left and the other could be moved to direct the animal up the center alley from either direction. Food reinforcement pellets were delivered into the maze through ¼ inch holes in the masonite on either side of the swinging door.

The maze was also adapted for olfactory cues. A system of negative pressure was set up by connecting two fans to the reinforcement side of the maze. The fans drew air out of the maze through two 2-inch holes. These holes were situated 10 inches in either direction from the center of the center alley and 6 inches from the base of the maze. The openings into the maze were covered on the inside by a fine wire mesh. Two similar holes in the choice point side of the maze allowed air to be pulled into the maze. This air was pulled through a two-way valve and two odor containers. The odor containers were two quart-size coffee cans filled with odor-soaked gauze. The valve allowed the odor-laden air from the two cans to be interchanged between the two intake holes in the side of the maze. This created streams of odor-laden air traveling around the circular arms of the maze, and the odors in these streams of air were interchangeable through the use of the valve. The top of the masonite partitions were covered with a rubber seal and a clear plexiglas sheet was laid over the top of the maze to make it airtight and facilitate the flow of air through the maze.

The valve was constructed with a sliding partition. When this partition was moved, it lined up hoses coming from the odor cans with those going to the holes in the maze. In one position, the valve would allow odor from can A to go to the right side of the maze and odor from can B to go to the left side of the maze. When moved to the second position, it allowed odor from can A to go to the right side of the maze and odor from can B to go to the left side. In this way, the interchanging of the odors allowed the olfactory cues to be random and independent in relation to the position cues.

The odors used in this apparatus were commercial cooking odors, specifically orange and wintergreen, as used by Jennings and Keefer (1969).

Procedure. After the preliminary handling period, the animals were randomly divided into three groups of six; the double-alternation to position "DAP" group, the double-alternation to odor "DAO" group, and the double-alternation to no odor or "DANO" group. The animals were all housed in pairs, each DAP animal with a DAO animal and the DANO animals with members of their own group. Each DAP animal was marked on the tail with indelible red ink and each DAO animal was marked with green ink. Each DANO animal was marked with either red or green so that members of cage pairs could be distinguished. Housing the animals in pairs assured that members of the DAP and DAO groups received similar handling.

Both members of a cage pair were run in the same experimental session. This meant that half the DAP animals and half the DAO animals were run on the first day and half of each group on the second day. The DANO animals were all run on the third day. This schedule was maintained throughout the experiment.

The DAO animals were tested on the double-alternation problem with odor as the relevant cues. They were trained to odors instead of to left or right. In other words they were trained to turn orange, orange, wintergreen, wintergreen instead of left, left, right, right. The location of an odor was determined by use of Gellerman sequences (Hilgard, 1958) 1 through 10. This was sufficient to assure that only odors were consistently associated with reinforcement.

The DAP animals were run under the same stimulus conditions as the DAO group, only they were trained to turn to the left and right instead of to the odors. They were trained to turn left, left, right, right, no matter in what order the odors were presented.

The DANO animals were run in the same way as the DAO group but odors were removed from the cans. This should have been an impossible task.

A "turn" in this experiment was considered as a complete run up the center alley and around the circumference of the indicated side back to the point of reinforcement.

Each group received training in double-alternation behavior through the use of two swinging doors in the maze. The training was divided into four sections or steps. The first step was to learn the first turn, the second step to learn the first two turns, the third step to learn three turns, and the fourth step to learn all four turns of the double-alternation response.

Because the first turn was the most difficult to learn, there were no set number of trials until the turn was learned. After an animal had learned the first turn, it was given 20 more trials on the first turn. During training each trial consisted of the number of turns to be learned (one during the first step of training), followed by reinforcement.

Each consecutive training step added another turn before the animal received reinforcement. There were twenty trials on each of the last three steps of training for all the animals. The training trials were run in blocks of five a day.

After the 80 training trials, each animal was run on 10 test trials, one a day. Each test trial consisted of an 8-turn sequence followed by reinforcement. The reinforcement was given no matter which eight turns were made.

The scoring was the same as that used by Diamond (1967). Each 8-turn test sequence had a maximum possibility of three correct double-alternation responses. Any four consecutive turns which followed the double-alternation pattern were counted as a correct response. A single turn therefore, could be counted in more than one correct double-alternation response. For example, the sequence llrrllrr contains three correct double-alternation responses. The sequence llrrllrrl contains two; the sequence llrllrrl contains one correct response.

Results and Discussion

After 64 test trials had been completed the results were scored for correct double-alternation responses by Diamond's (1967) method as specified above. The double-alternation scores for each group are tabled below in Tables 1, 2, and 3.

TABLE 1

DAO Group - Trained to Odor

Subjects	Correct Responses to Odor		Correct Responses to Position
2	8		2
4	6		0
6	10		0
Total Responses Correct	24	Total Responses Correct	2
Total Responses Possible	72	Total Responses Possible	72

TABLE 2

DAP Group - Trained to Position

Subjects	Correct Responses to Odor		Correct Responses to Position
3	10		2
5	3		1
7	3		0
9	4		0
Total Responses Correct	20	Total Responses Correct	3
Total Responses Possible	90	Total Responses Possible	90

TABLE 3

DANO Group - Trained to No Odor

Subjects	Correct Responses to Odor		Correct Responses to Position
13	8		0
Total Responses Correct	8	Total Responses Correct	0
Total Responses Possible	30	Total Responses Possible	30

The groups were scored on both odor and position problems although they were trained only on a specific double-alternation problem.

All groups made more correct double-alternation responses to odor than to the position dimension. There were only five correct double-alternation responses made to position over all three groups. The DAO group, trained to odor, ran 24 correct double-alternation responses to odor out of a maximum possible of 72 correct responses, but the single DANO animal tested and trained in the No Odor situation, ran 8 correct double-alternation sequences to odor out of a possible 30 correct responses. The DAP group, trained in double-alternation to position, made 20 correct responses to odor out of a possible of 90. Although it appears as if all three groups double-alternated to the odor cues, it is the belief of the author that none of the groups learned the problem.

The apparent double-alternation in the three groups can be traced to an effect of a certain pattern of responding to the position dimension. Single-alternation to position represented a pattern of responses which appeared to be partial double-alternation to odors as they were randomly interchanged according to the Gellerman sequences (Hilgard, 1958). Almost every correct double-alternation response to odor in this study can be accounted for in this way.

Whether the DAO group learned to double-alternate to the degree shown by the data or whether their behavior can be accounted for in the same way as the behavior of the other groups, is of course impossible to determine from the present data. It is, however, the firm conviction of the experimenter, that all the results, including the behavior of the DAO group, can be accounted for as an accidental manifestation of single alternation to position and the random sequence used. There is therefore no indication that the laboratory rat is capable of double-alternating to either odor or position as separate stimuli in the modified temporal maze used in this study.

CHAPTER III

EXPERIMENT II

Experiment I, while inconclusive as to the ability of the rat as an olfactory double-alternator, convinced the experimenter that the traditional temporal maze interfered with the rat's learning of the double-alternation problem. The maze situation with its hallways and doors represents a visually oriented problem into which the addition of olfactory cues only caused complication. In order to adequately present an olfactory problem, the method and design used must have an olfactory rather than a visual orientation. Taking advantage of the idea that odors are more strongly associated with objects than with directions, this study tried to use a task better suited to olfaction and more natural for the rat.

Method

Subjects. The subjects were 10 male hooded rats about 60 days old at the beginning of training. They were housed in pairs in the same room as the experimental apparatus, and were placed on a 22-hour water deprivation schedule. They were allowed free access to food throughout the experiment.

Apparatus. The apparatus consisted of a triangular compartment 25x25x14 inches along its edges. This represents a triangular area

14 inches wide at one end and converging to a narrow apex at the other with an overall length of 24 inches (see Figure 2). Beginning at the wide end of the compartment the floor sloped up for 18 inches increasing the height of the floor by 1 inch. The remaining 6 inches sloped sharply towards the apex of the compartment decreasing the height of the floor by 2 inches. The exterior walls of the compartment were clear plexiglas 12 inches high. In the wide end of the compartment, there were two hoppers each filling half of the 14-inch sides of the apparatus, extending 5 inches from the wall and separated by a 10-inch high partition. The hoppers were filled with 3/4 inch styrofoam balls. In order that the experimenter could distinguish the balls from each hopper, half the balls were washed a light orange and half were washed a light green with a dilute mixture of Rit dye. Half of each color was then treated with a Schilling commercial cooking odor by suspending them in a one-gallon jar over cloth soaked in the appropriate odor. A 14x24 inch All Purpose Kendall Cloth was folded and placed in the bottom of each gallon jar. These cloths were initially treated with 5 milliliters of commercial cooking odor and 2 milliliters were added after each experimental session. The jars were cleaned and the cloths replaced once a week. The styrofoam balls were suspended in the upper half of the jars by a 1/2 inch metal screen, and the jars were topped with a sealed lid. Half the orange balls were scented orange and half the green balls were scented wintergreen. They remained in the jars whenever they were not in use in the apparatus. Either the scented or the unscented balls were placed in the hoppers depending on the

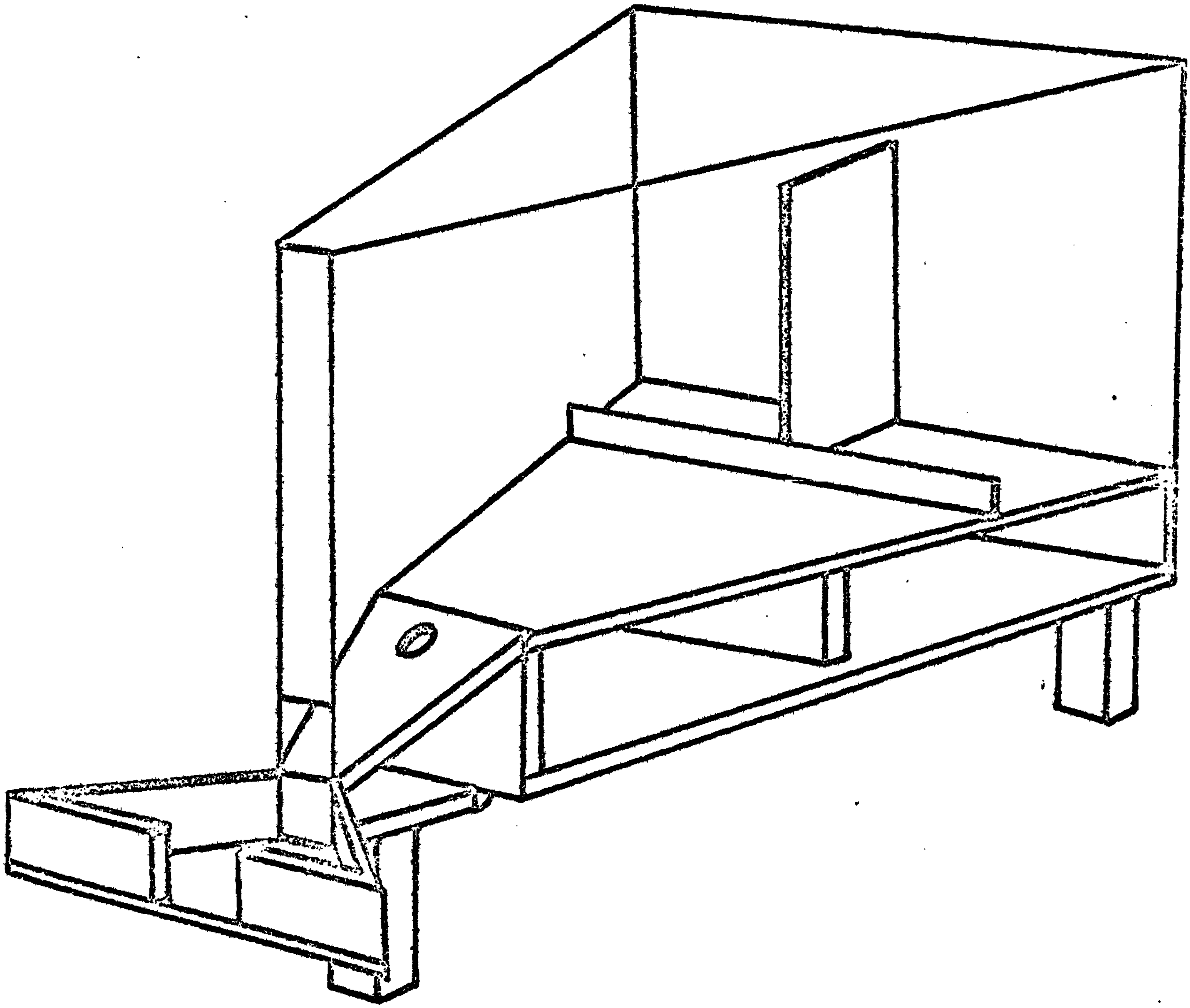

Figure 2. Olfactory, Temporal, Double-alternation Compartment, Experiment II.

group of subjects being run. The orange balls were always placed in the left hopper and the green balls were always placed in the right hopper.

A one-inch square opening in the apex of the compartment allowed the styrofoam balls to roll out of the apparatus. Whenever a ball was placed within six inches of the apex of the compartment it rolled down the incline and out of the apparatus. The balls then rolled into a tube which held them in the order they left the apparatus to aid in the recording of data.

Water reinforcement was delivered by a small metal cup through a 1/2 inch hole in the center of the floor 5 inches from the apex of the compartment. Reinforcement consisted of a four-second presentation of this cup.

Procedure. The subjects were randomly divided into two groups: the odor or "O" group with six members and the "NO" or no odor group with four members. The animals' tails were marked with indelible ink to distinguish cage pairs.

All the animals were put on a 22-hour water deprivation schedule. They were given water for two hours following each experimental session and then deprived of water through the next experimental session. All the animals were run every day and the experimental session was at the same time each day. The order in which the animals were run was reversed for each session.

The styrofoam balls were taken from the jars before each session and the hoppers were filled with 60 balls per hopper. The odor-treated balls were used with the O group and the untreated balls were used with the NO group.

The animals were first magazine trained. The experimenter then shaped the animals to carry the styrofoam balls from the hopper to the reinforcement point. After an animal had learned to carry the balls, the number of training trials began to be counted for that animal. A training trial consisted of an attempted double-alternation sequence followed by reinforcement, so that at the beginning of training every response defined a trial. In this study, the term "response" referred to the removal of a single ball from the hoppers. Double-alternation "sequence" referred to four balls in a double-alternation pattern. The number of responses per trial varied throughout the experiment depending on the stage of training attained and the number of incorrect responses made by an animal. The number of reinforcements per trial was always one reinforcement. After the training trials were being counted, the animal was run in ten trials a day. Before this time, the training sessions were limited to 15 minutes a day for each animal.

Discrimination training began as soon as the number of trials began to be counted. An animal was taught to discriminate between the two hoppers and only carry balls from one. Which hopper depended on the animal's preference.

After an animal learned to discriminate between the two hoppers by only carrying balls from one, the requirement was increased to two balls from the same hopper per reinforcement. In this way, the first two responses of the double-alternation sequence were shaped. After learning to carry two balls, the animal was trained to carry a third ball from the other hopper and then a fourth to obtain reinforcement.

An animal was double-alternating then, when it carried two balls from the same hopper and then two from the other on each trial. Any response which was part of a double-alternation sequence was considered a correct response. Mastery of the double-alternation problem was considered as 80% correct responses over 10 consecutive trials. An animal's total number of training trials was summed after reaching criterion or when the experimenter became convinced that the subject would show no more progress towards mastery.

Results and Discussion

Of the ten original subjects, only four (two from each group) learned the basic response of carrying the styrofoam balls from the hoppers to the reinforcement point. These four animals were run in more than 400 training trials with none of them reaching the 80% criterion level. However, three of the four animals did show some double-alternating behavior. Both animals from the odor group made more correct responses than either of the no odor animals and in the case of one animal from the odor group as many as 59.5% of its responses were correct over ten trials. The percentage of correct responses over 10 (see Table 4) and 50 consecutive trials (see Table 5) was computed for the four animals for comparison with criterion values of previous studies. These values represent the highest percentage correct that animal attained over a specific number of trials.

TABLE 4

Highest Percentage of Correct Responses Over 10 Consecutive Trials

Subjects		Highest Percentage Correct	Trials Required
Odor	A	59.5%	370
Group	B	40.0%	380
No Odor	A	35.0%	340
Group	B	0	470

TABLE 5

Highest Percentage of Correct Responses Over 50 Consecutive Trials

Subjects		Highest Percentage Correct	Trials Required
Odor	A	47.3%	370
Group	B	31.6%	420
No Odor	A	20.4%	370
Group	B	0	470

TABLE 6

Total Training Trials Run

Subjects		Total Training Trials Run
Odor	A	400
Group	B	430
No Odor	A	410
Group	B	470

CHAPTER IV

EXPERIMENT III

Experiment I indicated the need for a transition from a visual and directional task to one with an olfactory orientation. The results obtained in Experiment II suggested that the rat could double-alternate if this transition was made, but the transition was apparently incomplete and the method still interfered with the olfactory problem. The directional aspects were not completely removed. The apparatus still contained a "right" and a "left" hopper.

In Experiment III, it was hoped that the removal of this left-right distinction would make the double-alternation task as purely an olfactory problem as possible. This also removed any possibility of an animal having a directional body orientation following a response which could affect the next response. The new apparatus eliminated the necessity of spatially separating the discriminative stimulus from the instrumental response. The introduction of a sorting task randomized the presentation of odors in such a way that any discrimination had to be made on the basis of the olfactory cues rather than on the basis of spatial separation.

Method

Subjects. The Ss for this experiment were 10 male hooded rats about 150 days old at the beginning of training. They were housed in pairs in the same room as the experimental apparatus, and were placed on a 22-hour water deprivation schedule. They were allowed free access to food at all times throughout the experiment.

Apparatus. Three-fourths inch styrofoam balls were used in this study as in Experiment II. The balls were scented and colored in the same way as in the second study (see page 17).

The apparatus consisted of a rectangular compartment 8 inches wide by 15-1/2 inches long (see Figure 3). It was surrounded by a 12-inch high wall, opaque at the ends of the compartment and clear plexiglas on the sides. A sloped hopper for holding the styrofoam balls extended from one end of the compartment. The bottom of the hopper extended 4-1/2 inches into the compartment and sloped away from the compartment wall to a depth of 1 inch. The front edge of the hopper was bordered by a 1-1/2 lip setting out at a 45 degree ange. The main floor of the compartment began one inch directly below the lip of the hopper creating a one inch opening between the floor and the hopper that ran the width of the compartment. The first four inches of the main floor sloped up away from the hopper increasing the height of the floor by one inch. If a styrofoam ball was removed from the hopper and placed anywhere on this four inches of sloping floor, it would roll through the one-inch opening below the hopper and out of the apparatus. The remaining six inches of the main floor were level.

Water reinforcement was delivered by a small metal cup through a 1/2 inch hole in the center of the floor one inch from the hopper. A reinforcement consisted of a four-second presentation of this metal cup.

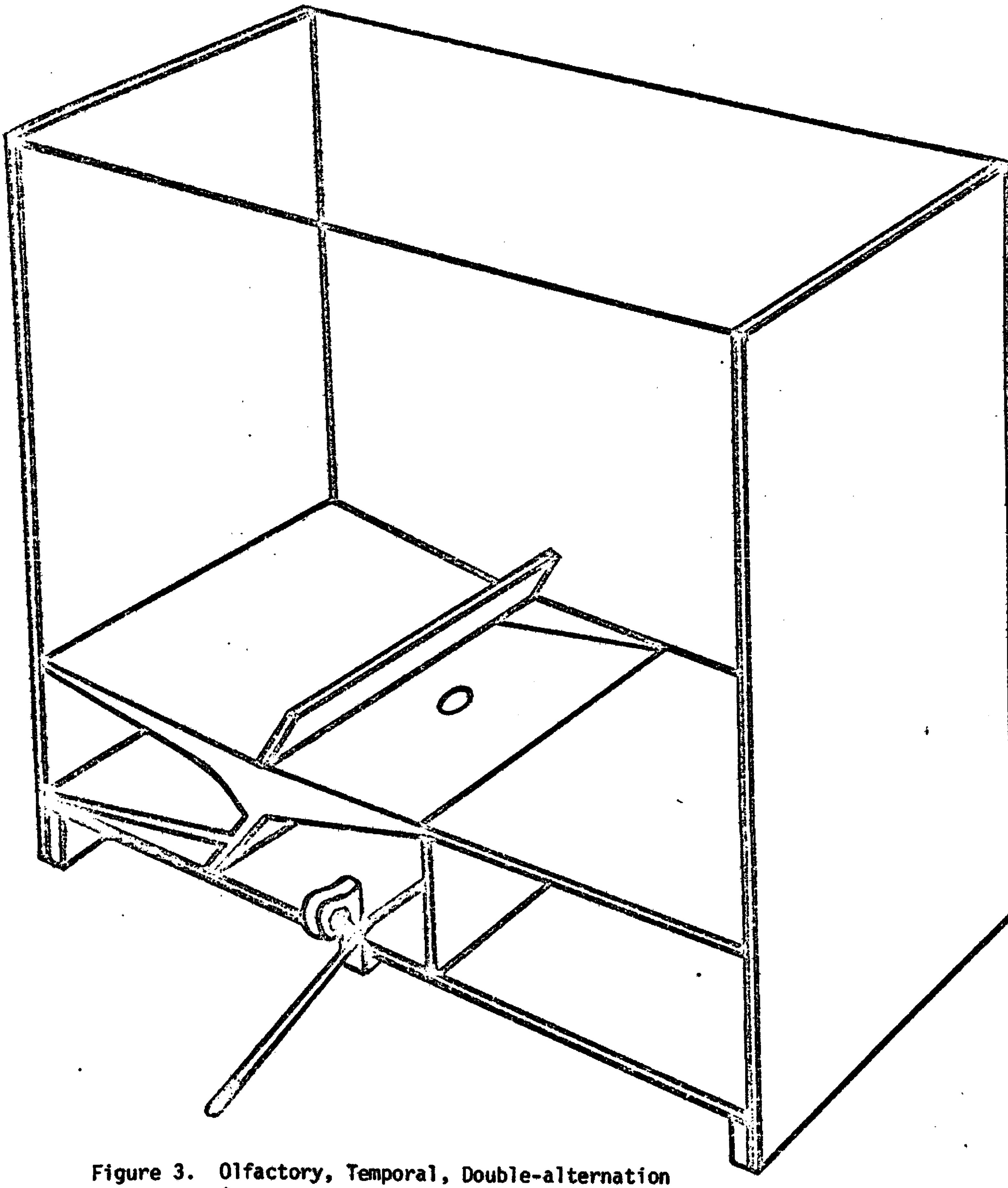

Figure 3. Olfactory, Temporal, Double-alternation Compartment, Experiment III.

Procedure. The Ss were randomly divided into two groups: the odor or "O" group with six members and the no odor or "NO" group with four members. The animals' tails were marked with indelible ink to distinguish cage pairs.

All the animals were put on a 22-hour water deprivation schedule. They were given water for two hours following each experimental session and then were deprived of water through the next experimental session. All the animals were run every day and the experimental sessions were at the same time each day. The order in which the animals were run was reversed for each session.

The styrofoam balls were taken from the jars before each session and the hopper was filled with 100 balls, 50 of each odor, thoroughly mixed. The odor treated balls were used with the O group and the untreated balls with the NO group. After each experimental session the balls were separated and returned to their original containers.

The animals were first magazine trained. The experimenter shaped the animal to take the balls from the hopper and drop them so they rolled from the apparatus. The number of training trials run by an animal began to be counted when it had learned this basic response. A training trial was defined as an attempted double-alternation sequence followed by reinforcement, so that at the beginning of training a trial consisted of a single response followed by reinforcement. Again, the term "response" refers to the removal of a single ball from the hopper, while double-alternation "sequence" refers to four responses in a double-alternation pattern. The number of responses per trial varied throughout the experiment depending on the level of training reached and the number of incorrect responses made by an animal. The number of reinforcements per trial was always one. After an animal had learned to make the basic response of removing balls from the hopper it was run in ten training trials a day; before this time, training sessions were limited to fifteen minutes per animal.

Discrimination training began as soon as the number of training trials began to be counted. An animal was taught to discriminate between the two odors by only being reinforced for removing one odor of ball from the hopper. Which odor depended on the animal's preference. After an animal had learned to discriminate between the two odors, the requirement was increased to two balls of the same odor per reinforcement. At this point, the animal had learned the first half of the double-alternation sequence. The second half of the sequence, or two balls of the other color, was then required on every other trial. As soon as an animal began to respond with pairs of both odors, all four responses were required on the same trial. Under this condition, an animal had to make the four responses of a double-alternation sequence to be reinforced. Only sequences of four consecutive responses in the double-alternation pattern were considered as correct double-alternation sequences, but an animal was reinforced whenever it responded with a pair of balls which had been proceeded by two or more of the other odor. For example, both "OOWW" and "WOWOO" would be reinforced, but only the first trial would contain a correct double-alternation sequence.

Results and Discussion

Of the ten original Ss, seven (four O animals and three NO animals) were run in over 600 trials. Three of the original ten animals were removed because of illness during the course of the experiment. None of the NO animals learned to discriminate between the two types of balls and showed no improvement even after completing 650 training trials. This indicates that within this apparatus it is impossible for the rat to double-alternate without the aid of olfactory cues. All four of the O animals learned to make this discrimination in an average of 160 training trials and all subsequently completed double-alternation sequences.

All four of the odor animals reached a performance level where a majority of their responses over ten consecutive trials were part of double-alternation sequences. One animal reached the criterion level used in Experiment II (80% correct over 10 consecutive trials) at which point the animal would have "mastered" the double-alternation problem. The highest percentage of correct responses over 10 and 50 consecutive trials is tabled below for each of the O animals (see Tables 7 and 8). These figures represent the number of responses which were part of correct double-alternation sequences expressed as percentages of the total responses made over 10 and 50 trials. For animal 5, as many as 81.6% of its responses over 10 trials were part of correct double-alternation sequences. As many as 72.7% of the responses made by animal 2 over 50 consecutive trials were part of double-alternation sequences.

TABLE 7

Highest Percentage of Correct Responses Over 10 Consecutive Trials

Subjects	Highest Percentage Correct	Trials Required
2	74.0%	460
3	72.7%	490
5	81.6%	570
6	62.0%	470

TABLE 8

Highest Percentage of Correct Responses Over 50 Consecutive Trials

Subjects	Highest Percentage Correct	Trials Required
2	72.7%	490
3	48.0%	530
5	68.2%	600
6	46.4%	530

Tables 4 and 5 (see page 22) contain similar values from the data in Experiment II. The odor group in the present experiment showed a substantial increase in double-alternation behavior over the odor group in Experiment II.

Figures 4 through 7 illustrate the percentage of double-alternation responses in 50 trial blocks for each of the O animals beginning after 300 training trials had been completed. Because of the training procedure

SUBJECT TWO:

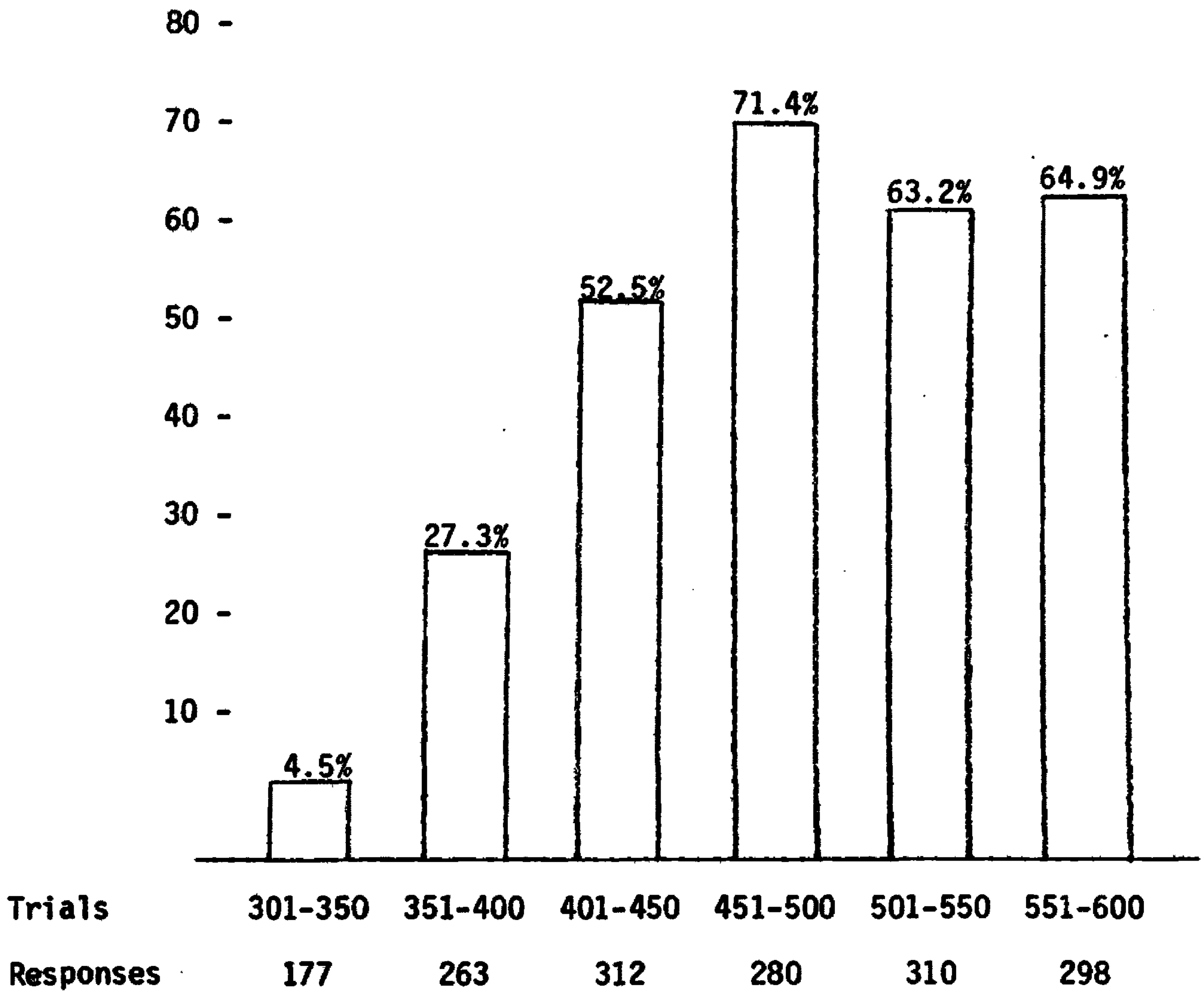

Figure 4. Animal No. 2. Percentage of double-alternation responses in 50 trial blocks with total responses contained in each 50 trials.

SUBJECT THREE:

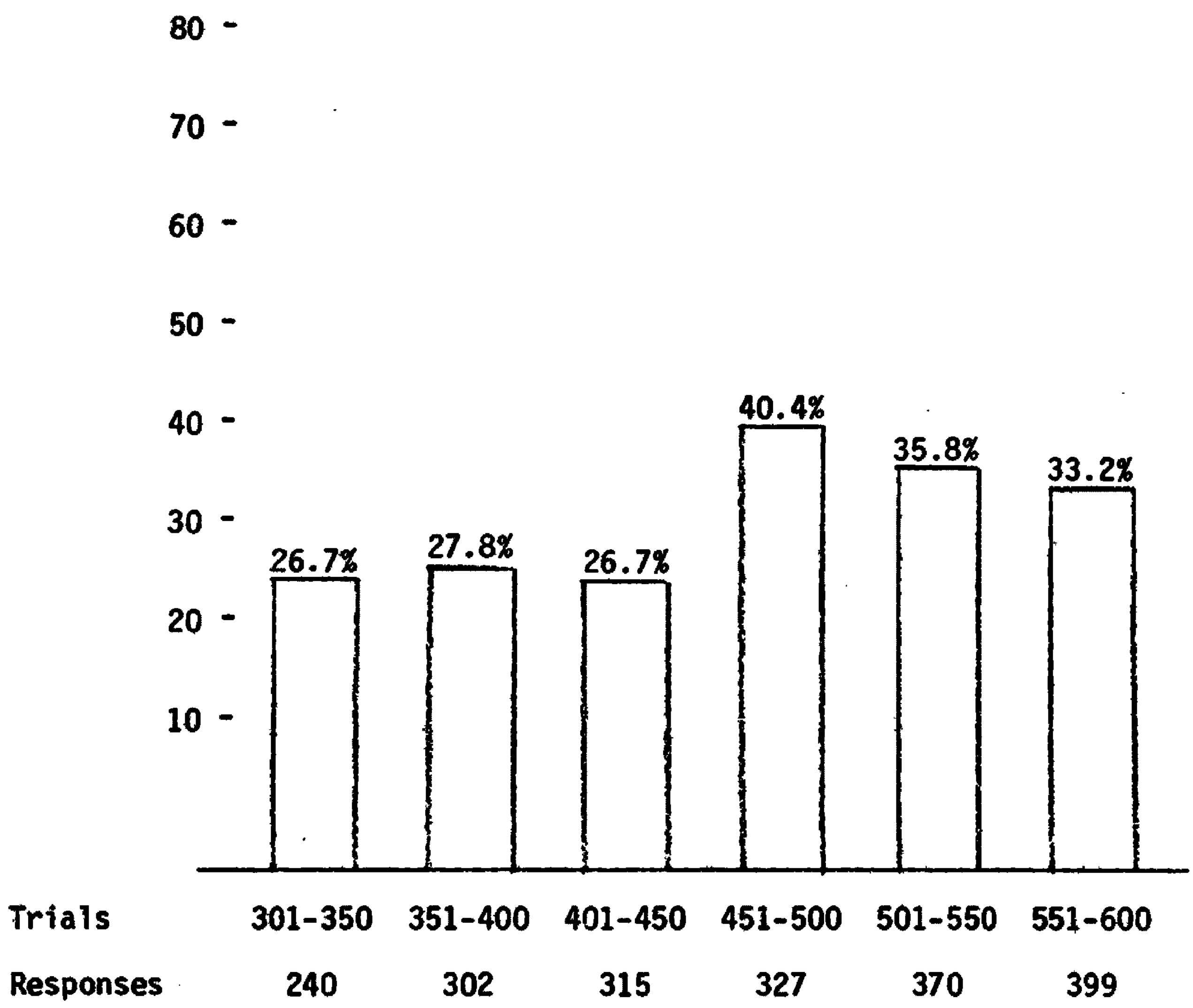

Figure 5. Animal No. 3. Percentage of double-alternation responses in 50 trial blocks with responses contained in each 50 trials.

SUBJECT FIVE:

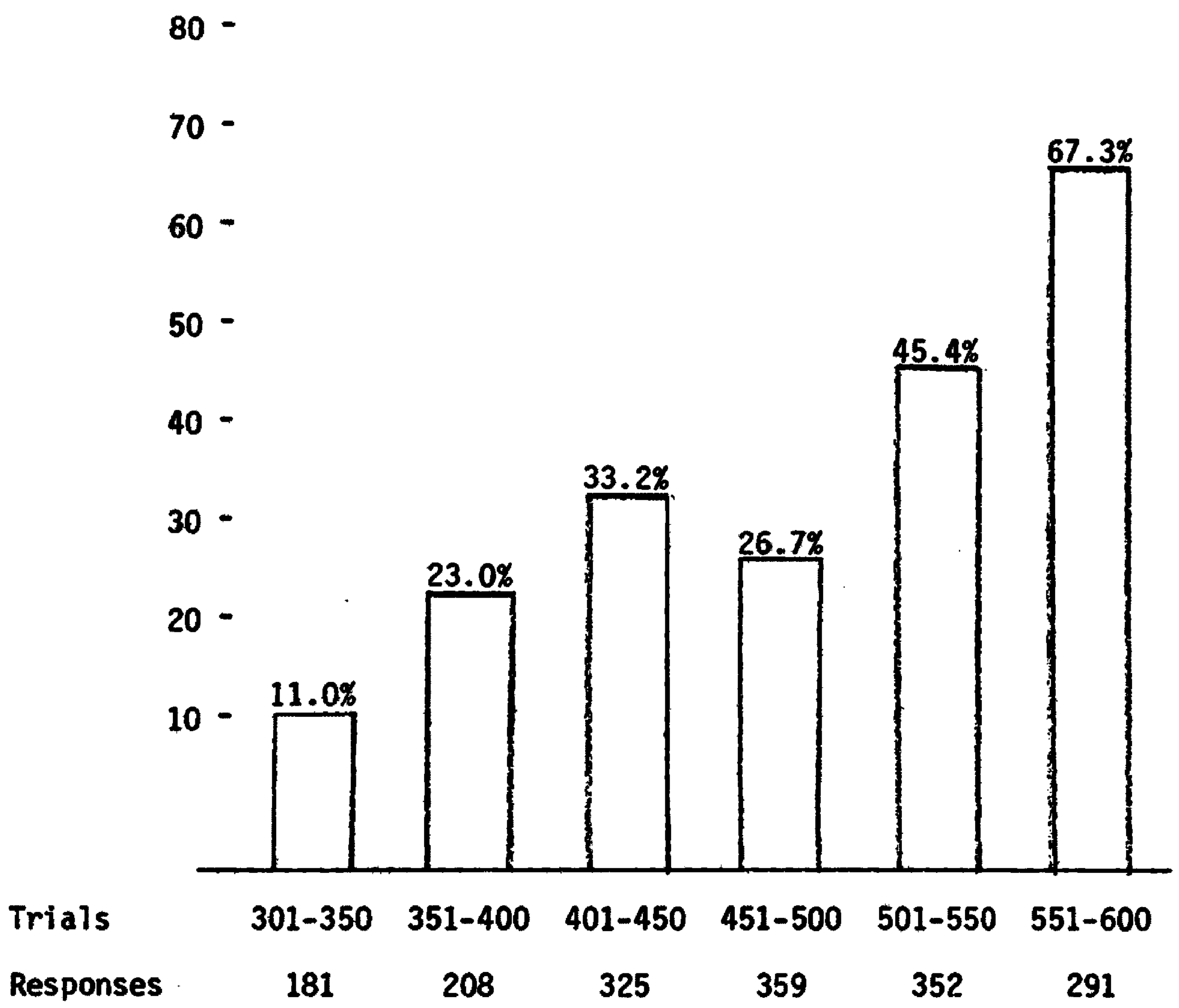

Figure 6. Animal No. 5. Percentage of double-alternation responses in 50 trial blocks with total responses contained in each 50 trials.

SUBJECT SIX:

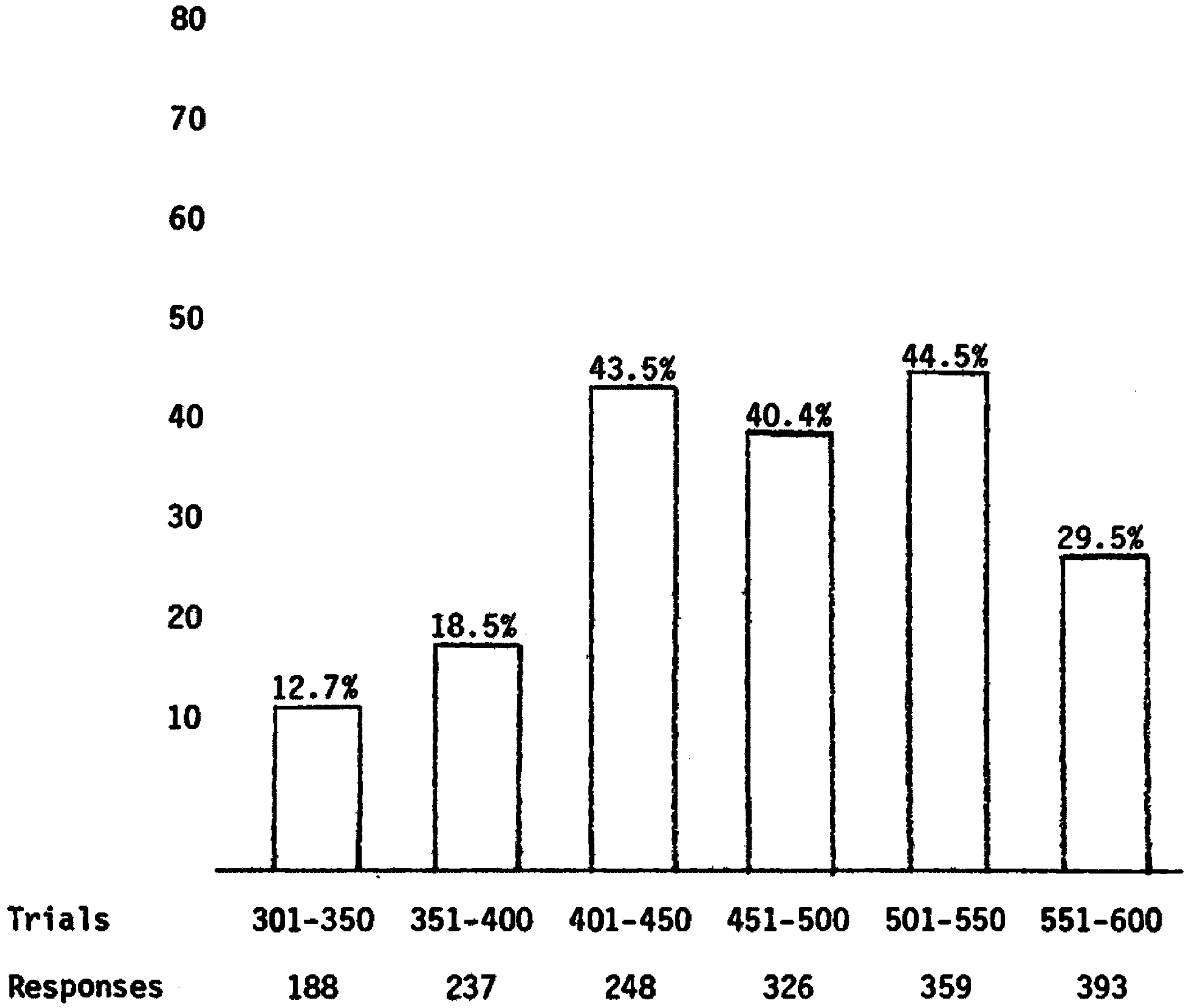

Figure 7. Animal No. 6. Percentage of double-alternation responses in 50 trial blocks with total responses contained in each 50 trials.

(see page 26), each block of 50 trials does not represent an equal number of responses, but rather an equal number of reinforcements. The number of responses included in each block of 50 trials is listed immediately below the trial block. Also, because of the effects of averaging, these figures do not necessarily represent an animal's best performance as do Tables 7 and 8.

The animals also showed a tendency towards single-alternation behavior which increased as training progressed. Animals 3 and 6 exhibited considerable amounts of single-alternation responding, and perhaps some of the decrease in performance on later trials could be attributed to this tendency.

The performance of animals 2 and 5 (see Figures 4 and 6) shows a definite acquisition of double-alternation behavior and level performance at percentage levels near 70% correct (72.7% and 68.2% over 50 consecutive trials). All four O animals, perhaps because of the similarity of the reinforcement schedule to an operant ratio schedule showed a tendency to respond rapidly as the number of responses per trial increased. The training procedure used in this study allowed a subject to make a limited number of incorrect responses prior to a double-alternation sequence with little effect on the rate of reinforcement. For example, all of the odor animals frequently made one or two rapid responses before completing a double-alternation sequence (e.g., "OWWOO" or "OWOOWW"). One such extra response on each trial represents a 20% rate of error. Perhaps with a method which would further limit these extra responses the percentage correct would be substantially increased. However, the present data represents a fair proficiency at a task previously considered impossible for the rat.

CHAPTER V

SUMMARY

This study represents a procedural transition through three separate olfactory, temporal, double-alternation experiments from an unsuccessful apparatus to one where moderate success was achieved on the double-alternation problem. There was no indication in Experiment I that the rat was capable of double-alternation in the traditional temporal maze when airborn olfactory cues were added. Experiments II and III introduced a procedural innovation which was better suited to the presentation of olfactory stimuli to the rat. The instrumental response required the manipulation of the stimulus object laden with odor and assured the subjects direct contact with the olfactory cues. Using this procedure in an apparatus with visual and spatial-separation cues, Experiment II allowed the rat to double-alternate up to levels of 35.0% correct over 10 consecutive tirals. With the addition of olfactory cues, performance was improved up to levels of 59.5% correct over 10 consecutive trials. In Experiment III further refinements in the apparatus removed all visual and spatial cues and on the basis of olfactory information alone, rats double-alternated at levels up to 72.7% correct over 50 consecutive trials and as high as 82.6% correct over 10 consecutive trials.

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